XII. *Memoir on the Degree of Selection exercised by Plants, with regard to the Earthy Constituents presented to their Absorbing Surfaces. By* CHARLES DAUBENY, *M.D., F.R.S. L.S. G.S., &c., Professor of Botany and Chemistry in the University of Oxford.*

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AMONGST the subjects recommended for consideration by the Chemical Sub-committee of the British Association for the Advancement of Science, during their Meeting at York in 1831, was that of the sources from which organic bodies derive their fixed principles; and as it was known to some of my friends that I had been engaged in certain inquiries that bore upon this subject, a request that I would undertake the investigation was accordingly entered upon the Minutes. I obtained, therefore, from this circumstance an additional motive for endeavouring, so far as my opportunities allowed, to prosecute the train of experiments which I had begun; and if I should scarcely yet have succeeded in determining to my entire satisfaction, whether or no there be any foundation for the idea sometimes entertained, that the earthy and alkaline principles which organized and living bodies contain are in any case elaborated by themselves, the reason must be sought for rather in the intricacy of the subject than in any want of disposition on my part to carry on an inquiry so recommended.

Incidentally, however, the results of my researches seem to lead to the establishment of a fact, which, as it serves to modify one of the conclusions deduced by the younger Saussure from his experiments on vegetation*, deserves, perhaps, a brief notice; and it is on this account, rather than for the sake of any new light I may have been able to throw upon the principal point in question, that I am desirous of laying before the Society the following details.

In the experiments that were made by Braconnot†, Schrader‡, and others,

* *Recherches Chimiques sur la Végétation*, 1804.

† *Annales de Chimie*, vol. lxi. p. 137.

‡ Gehlen's Journal, vol. v. p. 255.

with a similar intent to my own, the plants operated upon, in order that all external sources for the supply of earthy matter might be cut off, were made to vegetate either in washed sand, in sulphur, in pounded glass, in small shot, or in certain metallic oxides.

It occurred to me, however, that without placing them under circumstances so unnatural, and consequently so unfavourable to growth, the same end would be fulfilled if the seeds were sown in some earth which, though foreign to their constitution, agreed, nevertheless, more nearly in mechanical properties with those contained in the soils in which they were wont to grow.

It was with this intent that I was originally led to select as a soil for my plants the sulphate of strontian, which is obtained in abundance near Bristol, reduced to fine powder: and having found that the ashes of plants which had been reared in this matrix seemed to contain no trace of the earth, I was led, in the next place, to try whether this might be owing merely to the insolubility of the substance in question; for which reason I varied the experiment by watering my plants with a weak solution of nitrate of strontian.

It will appear from the subsequent details, that in either form of the experiment lime, and not strontites, was the earth that presented itself; but as in proportion to the care that had been taken to exclude any external source of supply for earthy matter, the quantity obtained from the ashes grew less and less, it would be rash to infer, from the small excess of lime which was detected, any power belonging to the plant of forming it, when not supplied from without.

Should it, however, appear that a vegetable, which, though not perhaps in full vigour, was at least in a growing and healthy condition, remained in contact with strontian, both in the state of sulphate, and likewise in that of nitrate dissolved in water, for months together without absorbing any portion, and that, although in want of earthy matter, as its laxity of fibre evidently betrayed, the conclusion would seem to follow, that plants have to a certain extent the power, as living agents, of rejecting such substances as, without being poisonous, are unusual to them, and probably unfitted for their œconomy and structure.

Omitting some previous experiments, of which I have preserved no correct notes, I will in the first instance refer to one made in 1827, in which grasses and trefoils of various kinds, which had been watered from time to time with a solution of nitrate of strontian, were found on examination to possess no trace of this earth *.

In the above instance, however, as the plants had grown in common garden mould, all that could be inferred was, that when lime and strontian are both presented in a state of solution to their roots, they select the former, and reject the latter.

In 1829, the seeds of various plants, such as the garden radish (*Raphanus sativus*), the cabbage (*Brassica oleracea*), the garden bean (*Vicia Faba*), hemp (*Cannabis sativa*), &c., were sown in soils containing various proportions of sulphate of strontian, with or without manure, and amongst the rest, one in which no other ingredient, except this earth, was present in any quantity. The plants grew up, and when they had arrived at maturity, were collected, burnt, and their ashes examined. No strontian, however, could be detected in any one of them, not even in that where the matrix consisted almost wholly of the earth in question.

In 1831, the experiments were conducted with rather more attention to

* I will state, for the satisfaction of chemists, the method I pursued to determine whether strontian was or was not present.

After washing off the alkaline salts from the ashes by lixiviation in warm distilled water, I digested the residuum in diluted nitric acid. This first acted upon the earthy carbonate, and afterwards upon the earthy phosphate. The solution in nitric acid consequently contained both. The phosphate being thrown down by ammonia, the nitrate remaining in solution, rendered exactly neutral, was evaporated by a heat never exceeding 212°, in a flask, and when dried, the mouth of the vessel was closely stopped by a cork. When cold, alcohol of the sp. gr. of ·815 was poured upon it, which would dissolve all the nitrate of lime. If there was no undissolved residuum, the absence of strontian from this portion of the ashes might be fairly inferred. If there was any, I generally digested it with a solution of carbonate of soda, and after filtering, heated the earthy residuum in a covered capsule, so as to expel the carbonic acid. A small quantity of distilled water would then generally dissolve the whole; and if the addition of a drop or two of sulphuric acid to this solution did not render it turbid, I felt myself justified in concluding that no strontian was present. The precipitate, if any, was concluded to be sulphate of strontian.

A similar procedure was adopted with reference to the earthy phosphate, and likewise to that portion of the ashes which remained undissolved by the nitric acid upon its first application. In both cases, digestion with an alkaline carbonate reduced the earthy matter to a fit condition to be acted upon by nitric acid, and the subsequent steps pursued to determine the presence of strontian in it corresponded with those already detailed.

accuracy. 1124 grains of scarlet kidney-beans (*Phaseolus multiflorus*) were sown in a box containing about 290 lbs. of powdered sulphate of strontian, which had been ascertained to be free from alkaline matter, but to contain 2 per cent. of carbonate of lime, and about ½ per cent. of alumina. The box was placed in an open situation, exposed to sun and rain; and when the plants reared from these seeds had come to maturity, they were cut down and burnt. An account was then taken of the weight of the ashes remaining after the combustion had been completed, and of the fixed principles obtained from them, first, by lixiviation in water; secondly, by digestion in nitric acid; and thirdly, by treating the remainder with an alkaline carbonate, and then, again, with the same acid as before. A similar process was gone through with the same quantity of the kidney-beans as that of which the plants examined had been the produce.

The following will present a tabular view of the results obtained.

Subject of the Experiment.	Where sown.	Weight of its ashes.	Soluble portion of these ashes			
			In water.	In nitric acid,		
				Without previous treatment.	After having been acted upon by an alkaline carbonate.	
					Earthy phosphate.	Earthy sulphate.
Seeds of *Phaseolus multiflorus*, 1124 grs.	....	106	6·7	0·67	0	0
Ditto, 1124 grs.	In a soil chiefly composed of sulphate of strontian, in a garden ...	283	11·3	131·5	31·0	2·3

Now the aqueous solution represents the amount of alkali combined either with the phosphoric or carbonic acids; the solution in nitric acid without previous treatment, the earthy carbonates and phosphates*; that in nitric acid, after the action of an alkaline carbonate, the earthy sulphate, with that por-

* The difference in the quantity of lime to be inferred from 100 of phosphate and 100 of carbonate was only as 53 to 56.

tion of the phosphate which had escaped the previous action of the acid. These were not distinguished with any precision one from the other, because my object was merely to show that a large increase in earthy matter had resulted from the process of vegetation; but the several portions were all minutely examined for strontian, of which they furnished no trace.

The same year I endeavoured to ascertain how much of this increase might be attributable to the rain, and the matters brought with it, by the following experiment:

I procured six oblong boxes, of nearly equal size, coated internally with sheet zinc, two of which were filled with sulphate of strontian, two with powdered Carrara marble, and two with sea-sand, well washed both with water and muriatic acid. Of these, one of each kind was placed in a greenhouse, where they were protected from dust and rain; and the same number in an open garden, where they were exposed to both*. There was also placed in the garden a fourth box, of twice the dimensions, filled only with common mould. In each of the six smaller boxes were sown 780 grains of the seeds of the winged-pea trefoil (*Lotus tetragonolobus*), in the largest one double that quantity; and when the plants had severally grown up in their respective situations, they were cut down, dried, reduced to ashes, and examined, a comparative analysis being at the same time made of a quantity of the seeds equal to that planted in each of the six smaller boxes.

It will be seen from the following tabular view of the results obtained, that in every one of these cases there was an excess of earthy salt beyond that existing in the seeds, and in one case an excess of alkaline; those even which had vegetated in a soil chiefly consisting of sulphate of strontian obtaining, nevertheless, an increase of earthy matter, and this containing not even a trace of strontites, but consisting wholly of lime. In other respects the quantity of earth obtained appeared to keep pace with that in which the plant was supplied with it from without. Thus, the largest amount of lime was from the plants that had grown in Carrara marble, and of silex from those that had grown in sand. On the other hand, the great increase of calcareous salts in the produce of the seeds that had grown up in the garden, in a soil consisting of sul-

* I am indebted to Professor Buckland for the use of a garden, in which the boxes were placed during the time the experiment lasted.

phate of strontian, indicates how much is owing to the quantity of earthy matter brought to it by the rains.

The following is a tabular view of the results of the above-mentioned experiments.

Subject of the Experiment.	Where sown.	Weight of the plant when dried.	Weight of its ashes when burnt.	Portion soluble In water, Consisting of Potass combined with carbonic and phosphoric acids.	Portion soluble In nitric acid, Consisting of Same combined with carbonic and phosphoric acids.	Portion insoluble in these menstrua. Chiefly siliceous.
Lotus tetragonolobus, seeds 780 grs.	....	....	30	5·2	3·4	only a trace.
Same quantity of ditto.	*In a Greenhouse.*					
	SOIL. Sulphate of strontian.	4002	60	very small.	17·15	not estimated.
Ditto.	Carrara marble.	2233	67·5	1·8	20·9	not estimated.
Ditto.	Sea-sand.	1135	34·3	4·1	6·0	not estimated.
Ditto.	*In a Garden.*					
	SOIL. Sulphate of strontian.	4862	94·0	0·72	27·2	not estimated.
Ditto.	Carrara marble.	3267	64·5	a trace.	28·2	1·5
Ditto.	Sea-sand.	2957	67·0	a trace.	16·0	8·8
1560 grs. of Ditto.	Common garden mould ..	10534	164·50	33·6	27·70	10·0
or 780 grs.	In ditto.	5267	82·25	16·8	13·85	5·0

In 1832 I made similar arrangements to those just alluded to, with the addition of a fourth box, containing washed flowers of sulphur, and the omission of those which the preceding year had remained in a garden. The four boxes employed being placed in a greenhouse under cover, 300 grains of barley were sown in each of them, and they were severally moistened, as they seemed to require, with distilled water, containing in every ten gallons two ounces of nitrate of strontian. The plants were treated in the same manner as on the preceding year, though, it is to be remarked, they did not thrive equally well. They were not cut down until the whole of the water had been expended upon them; so that we may calculate about half an ounce of nitrate of strontian to have been applied to the roots of each.

The following is a tabular view of the results obtained.

Subject of the Experiment.	Where planted.	Weight of the dried plant.	Weight of its ashes.	Soluble portion of these ashes: In water.	In nitric acid, Without previous treatment.	After being acted on by an alkaline carbonate. Earthy phosphate.	Earthy sulphate.	Portion insoluble in these menstrua.
Barley (*Hordeum vulgare*), 300 grs. . . .	....	....	7·7	1·53	1·68 N.B. Consisting entirely of phosphate.	......	·45	2·04
	In a Greenhouse. Soil.							
300 grs. of ditto.	Sulphate of strontian.	383	61	13·3	17·0*	3·6	1·3	0·9
Ditto.	Carrara marble.	230	34	7·8	14·5	......	2·5	0·8
Ditto.	Washed sea-sand.	260	45	10·5	5·9	0·9	2·5	2·1
Ditto.	Flowers of sulphur.	78	7	0·9	4·0	none.	none.	0·1

At the same time at which the above four samples had been planted, 100 grains of barley were sown in flowers of sulphur, and moistened only with distilled water. This latter yielded only 16 grains of the dried barley-straw, and being burnt, left no more than 1 grain of ashes,—a quantity so much less than what would have proceeded from the 100 grains of barley, of which it was the produce, that I thought it useless to carry the examination of them any further †.

* These salts for the most part consisted of nitrates of lime derived from the action of nitric acid upon the earthy carbonate, of which the greater part consisted.

† M. Laissaigne, as quoted by M. Richard, made an experiment to the same effect and with similar results to this of mine. But his mode of conducting it appears in this respect unsatisfactory, in as much

I may remark, that all the four samples of barley-straw, which had been watered with the strontian solution, were examined with care in the hope of detecting in them the presence of that earth; but the earthy matter obtained from those planted in sea-sand and in sulphur presented not even a trace of it, that from sulphate of strontian only 0·3 of a grain, that from Carrara marble only 0·4,—an amount beyond comparison smaller than what would have been present had it been secreted with the same readiness as a calcareous salt would have been. Yet that the presence of nitrate of strontian did in some measure contribute to the growth of the plant may be inferred by comparing the amount of barley-straw obtained from the flowers of sulphur watered with that solution, and that from the same matrix moistened merely with distilled water.

In the first case, the barley-straw weighed 78 grains, and the ashes derived from it 7; whilst in the second, that from an equal amount would have yielded 48 grains, and its ashes only 3 grains.

The same year a similar train of experiment was pursued with the *Lotus tetragonolobus*, or Winged Pea Trefoil.

Six hundred grains of the seeds of this plant were sown in each of the boxes employed in the foregoing experiments. They were moistened from time to time, as before, with water containing two ounces of nitrate of strontian to the ten gallons, and they were not cut down until the whole of this water had been expended upon them.

In order the better to arrive at an approximation to the actual increase of solid matter obtained during the process of their vegetation, the plants were taken up by their roots, and the adhering earthy matter carefully detached; but lest this should have been incompletely effected, the stems and other parts

as the plant was taken up before it could be expected, in the natural course of things, to have begun to draw upon external sources for a supply of earthy matter. It is well known that the albumen of the seed is expressly provided for the nutriment of the infant plant; hence, the first effort of germination is to produce nothing more than an evolution of matter previously existing in the seed, and it is only in the future progress of the plant towards maturity, after this internal supply has been exhausted, that we can hope to trace, if at all, any increase of earthy or alkaline matter. Now M. Laissaigne's experiment was stopped at the end of fifteen days, a period too short to allow of much accession of earthy matter from without to have taken place.—See Richard's Elements of Botany, English Translation by Dr. Clinton, p. 213.

of the plant which had been above the surface of the soil were separated, so that these at least might be considered free from any ingredients, except such as constituted integrant parts of its actual composition.

The several portions of these respective samples having been weighed, reduced to ashes, and examined in the usual way, the results were obtained indicated in the following Table, in which the stem, leaves, and flowers are comprehended under the head of "Parts above ground"; the roots and seeds which had not germinated, under the head of those "under ground".

Subject of the Experiment.	Where sown.	Weight of the dried plant.	Weight of its ashes.	Portion soluble in water.	Portion soluble in nitric acid.
Seeds of the *Lotus tetragonolobus*, 600 grs. ..	....	....	23	4·0	2·6
	In a Greenhouse.	*Parts.*			
	Soil.	Gr.			
Ditto. Same quantity.	Sulphate of strontian.	above ground ... 170	22	6·65	2·65
		under ground ... 107	40	0·48	5·60
		277	62	7·13	8·25
Ditto.	Carrara marble.	above ground ... 150	19	3·70	16·3
		under ground ... 152	34	3·20	37·0
		302	53	6·90	53·3
Ditto.	Washed sea-sand.	above ground ... 34	5	2·3	1·4
		under ground ... 100	6	1·4	1·7
		134	11	3·7	3·1
Ditto.	Flowers of sulphur.	above ground ... 100	6	2·6	2·9
		under ground ... 108	5	2·6	1·9
		208	11	5·2	4·8

The aqueous solution consisted chiefly of potass combined with the carbonic or phosphoric acids, together with a slight admixture of sulphate of lime, whilst the portion which the acid dissolved was chiefly composed of an earthy carbonate and phosphate.

Now I satisfied myself, by a minute examination, that the acid solution derived from the stems contained no trace whatever of strontian, although a small portion appeared to be present in, or at least adherent to, the roots.

In other respects the results indicate decisively a connexion between the quantity of earthy matter contained in the plant, and the readiness with which it is supplied with it from without; since, even if we confine ourselves to the portions above ground, where there can be no suspicion of any foreign admixture, it will be seen that the largest amount of calcareous earth was obtained from the straw which had grown up in Carrara marble, and that the excess of it over that in the seeds was in the other instances but inconsiderable.

The last experiment of the kind I shall allude to was made in the present year.

Two boxes only were this time employed, the one filled with sea-sand, the other with Carrara marble. In each of them 500 grains of barley were planted; they were watered, as before, with a weak solution of nitrate of strontian, and were protected from dust and rain by being placed under cover in a greenhouse. The plants obtained, being burnt, were treated in the same manner as before, and rigorously examined for strontian. Of this, the roots of both samples appeared to contain a trace, though the largest amount did not exceed $\frac{1}{10}$th of a grain. On the other hand, the parts which were above the surface, and therefore free from all contact with the soil, appeared to be entirely destitute of this earth. Nevertheless every portion, both of the sand and of the Carrara marble, was found impregnated with the nitrate of strontian that had been held in solution by the water with which the plants had been moistened.

I fear the conclusions that may be legitimately deduced from the above experiments will hardly be deemed of sufficient novelty and importance to repay the labour and time they have cost me; since, in so far as the main point is concerned, they serve only to confirm in an indirect manner the conclusion, which both analogy and experiment concur in establishing, namely, that if plants do in some cases obtain fixed principles which cannot be traced to any external source, yet the quantity of such substances which enters into their system is always less in proportion to the pains taken to cut off a supply. Hence the inference would seem to be, that the indications of a contrary description that sometimes present themselves are fallacious, resulting from the many imperceptible channels by which earthy and alkaline matter may obtain admission to the juices of a plant*.

Had I not very early in the course of these experiments been led to despair of excluding the minute but continual supplies, which are probably brought by the very air and water which come into contact with the absorbing surfaces of every vegetable, especially in the centre of a large town, I should not have remained satisfied without purifying the sulphate of strontian in which the seeds were sown from the other earths with which I found it to be mixed. But the labour of getting rid of these ingredients seemed to be uncalled for with reference to the objects to which I found it necessary to confine my inquiries; since even had I employed the earth in a state of perfect purity, and detected an excess of lime in the plants reared in it beyond that contained in their seeds, still I should not have been justified in inferring the actual generation of earthy matter, any more than I have felt myself to be from the similar result I obtained when flowers of sulphur were the matrix in which the plants had vegetated.

The faculty, however, possessed by them of rejecting strontian, even when presented to the absorbing surfaces of their roots in a state of solution, would seem sufficiently substantiated; and an analogous circumstance may be cited in the animal kingdom, if I can rely upon an experiment which I made several years ago, that of confining some hens of the Guinea-fowl during the breeding-season in a place where they could obtain no other earth, except some powdered sulphate of strontian, which they appeared to devour greedily.

Yet only a minute trace of this earth was discoverable in the shells of their eggs, of which those laid during the first part of their confinement retained their natural hardness, but those of later production were as soft as if the birds had been entirely debarred from every kind of earthy matter.

It may be asked, whether the strontian is taken first into the system, and afterwards excreted from it, or whether the spongioles of the roots refuse it

* The case which I should be most disposed to bring forwards in support of the contrary opinion is that of the phosphoric acid, which forms so abundant an ingredient in all animal structures. Is its quantity sufficiently accounted for by that introduced into the system by the food taken in? On this subject I hope at some future time to complete some experiments. See also Dr. Prout's Paper on the phosphate of lime existing in the young chick before the egg is hatched.

admission. The latter supposition seems the more probable one, since, if we adopt the former, we ought to be able always to find traces of the earth diffused throughout the vegetable tissue; and I may relate an experiment of my own, which seems to confirm it, undertaken after the plan of those by means of which the ingenious M. Macaire of Geneva established his important doctrine with respect to the excretory function discharged by the roots of plants.

A small *Pelargonium* was taken out of its pot, and its roots divided into two nearly equal bundles, one of which had its extremities immersed in a glass containing a weak solution of nitrate of strontian; the other, in one containing pure distilled water.

After a week had elapsed, the water contained in the second glass was tested; but no strontian could be discovered in it, though a single grain in one pint of water would have been readily detected by my method. Hence it would seem that the strontian is not excreted by the roots.

Yet this power of rejecting the earth in question, if possessed by the plant, must be held compatible with that of absorbing the water containing it, with which its roots are in contact. I took out of the ground a small Lilac (*Syringa vulgaris*), and introduced its roots into a glass globe containing seven pints of a weak solution of nitrate of strontian. In about a fortnight the quantity was reduced to three pints, the remainder having for the most part been absorbed by the roots; for evaporation was prevented by covering the surface of the water with a stratum of olive oil, and the mouth of the vessel with a cork. Unluckily, the original quantity of salt had not been estimated; but it was found that what remained in the water at the close of the experiment yielded 69·4 grains of sulphate of strontian, equivalent to 39·2 of the earth. The four pints of water therefore consumed, if they had passed through the organs of the vegetable charged with their original quantity of nitrate of strontian, would have carried into its circulation 22·4 grains of this earth; and as the water was absorbed at the average rate of about $4\frac{1}{2}$ ounces per diem, it follows that more than a grain and a half would have been carried daily through the substance of the plant, supposing the salt to have been taken up in the same ratio as the water. Now on burning the plant, and examining its ashes, a trace of strontian certainly was detected, but its whole amount did not reach the $\frac{1}{5}$th of a grain, that is, 2 per cent. of the whole quantity of earthy matter present, my analysis indicating

	Gr.
Of lime	7·30
— strontian	0·18
Total quantity of earth . . .	7·48

The conclusion to which I have been led by the foregoing experiments may appear at first sight inconsistent with those deduced by M. de Saussure in his elaborate work on vegetation before referred to, in which he has shown that some poisonous substances, such, for example, as salts of copper, are freely absorbed by the roots of vegetables, and retained in considerable quantities in their tissue.

But it will be recollected, that this philosopher himself accounts for the circumstance by the disorganization which such bodies, by their presence, occasion in the fibres of the roots.

I have myself found that when a *Pelargonium* had a portion of its roots immersed in a solution of bichromate of potass, a trace of this salt was conveyed into a second glass containing distilled water, which had no connexion with the former, except through the medium of a parcel of the roots which dipped into it. Nor was this owing to capillary attraction, for the same effect did not take place in another experiment, in which the roots were detached from the body of the plant, and therefore acted as dead matter; and, moreover, the salt was detected by appropriate tests applied to the stems and leaves.

In this instance, then, the substance was seen to circulate through the whole texture of the vegetable, and ultimately to be excreted by its roots; and a similar result was obtained in the case of another plant, in which a solution of proto-sulphate of iron had been dissolved in the water in contact with its extremities*.

* That is to say, the salt was detected by ferro-cyanate of potass in many parts of the stem and branches; but it did not reach above a certain point, nor was it excreted by the roots, this difference arising from the absorption of oxygen by the salt, which, being thereby converted into a persulphate, became insoluble in the juices of the plant, and consequently clogged up the canals by which the sap is conveyed.

But in all these instances the poisonous quality of the substance was evinced by the more or less rapid decay of the plant that had imbibed it; whereas, where nitrate of strontian was employed, the functions of life appeared to go on for a considerable time without material obstruction.

Upon the whole, then, I see nothing, so far as experiments have yet gone, to invalidate the conclusion, to which the preceding facts appear to lead, that the roots of plants do, to a certain extent at least, possess a power of selection, and that the earthy constituents which form the basis of their solid parts are determined as to *quality* by some primary law of nature, although their *amount* may depend upon the more or less abundant supply of the principles presented to them from without.